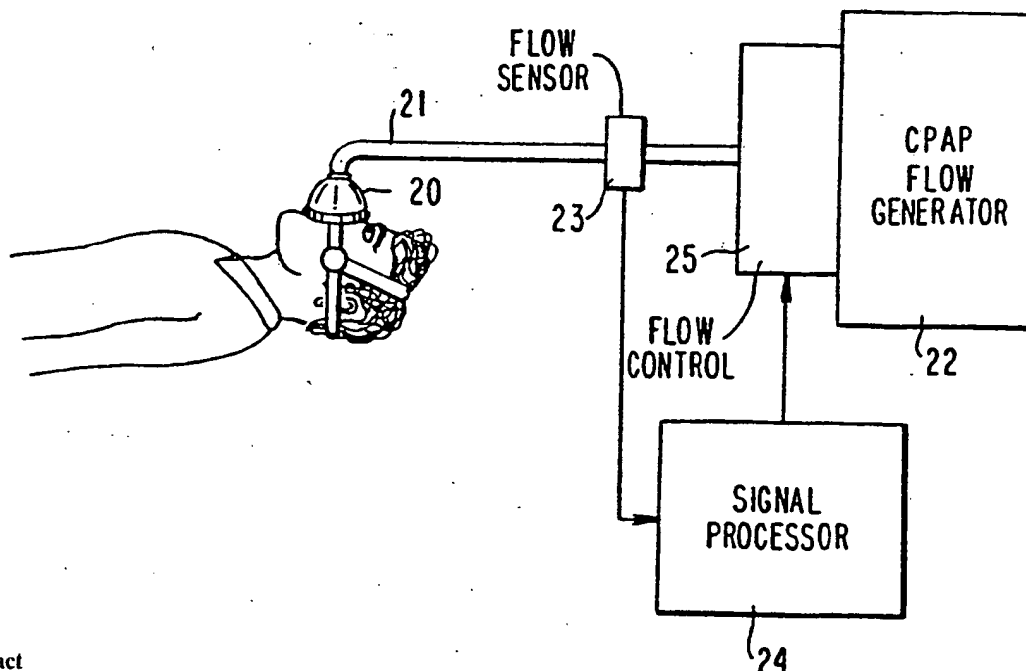




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**(54) Title:** APNEA TREATMENT USING ADJUSTABLE POSITIVE AIRWAY PRESSURE

**(57) Abstract**

In the treatment of obstructive sleep apnea, a CPAP flow generator (22) is employed to direct air to a nasal mask (20) fitted to a patient. The airflow from the generator is monitored, and the flow and/or pressure is increased through signal processor (24) when the waveform of the air flow exhibits characteristics corresponding to flow limitation. The generator may be controlled to repetitively test for waveform variations, in order to adjust the CPAP flow to the minimum level that does not produce flow limitation.

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## APNEA TREATMENT USING ADJUSTABLE POSITIVE AIRWAY PRESSURE

## FIELD OF THE INVENTION

This invention relates to a method and apparatus for adjusting the positive airway pressure of a patient to have an optimum (e.g. minimum) value, in the treatment of obstructive sleep apnea,

## BACKGROUND OF THE INVENTION

Obstructive sleep apnea syndrome (OSAS) is a well recognized disorder which may affect as much as 1-5% of the adult population. It is one of the most common causes of excessive daytime somnolence, and it is the single most frequent reason for referral to sleep disorder clinics.

The syndrome is characterized by the intermittent obstruction of the upper airway which occurs during sleep. The obstruction results in a spectrum of respiratory disturbances ranging from the total absence of airflow (apnea) to significant obstruction with or without reduced airflow (hypopnea and snoring), despite continued respiratory efforts. The morbidity of the syndrome arises from hypoxemia, hypercapnia, bradycardia and sleep disruption associated with the apneas and arousals from sleep. OSAS is most frequent in obese males, and is associated with all conditions in which there is anatomic or functional narrowing of the upper airway, as in heavy snoring.

1           The pathophysiology of OSAS is not fully worked out. However, it is  
2 now well recognized that obstruction of the upper airway during sleep is in  
3 part due to the collapsible behavior of the supraglottic segment during the  
4 negative intraluminal pressure generated by inspiratory effort. Thus, the  
5 human upper airway during sleep behaves as a Starling resistor, which is  
6 defined by the property that the flow is limited to a fixed value irrespective of  
7 the driving (inspiratory) pressure. Partial or complete airway collapse can then  
8 occur associated with the loss of airway tone which is characteristic of the  
9 onset of sleep and may be exaggerated in OSAS.

10           Since 1981, continuous positive airway pressure applied by a tight fitting  
11 nasal mask worn during sleep has evolved as the most effective treatment for  
12 this disorder, and is now the standard of care. The availability of this non-  
13 invasive form of therapy has resulted in extensive publicity for apnea and the  
14 appearance of large numbers of patients who previously may have avoided the  
15 medical establishment because of the fear of tracheostomy. Increasing the  
16 comfort of the system, which is partially determined by minimizing the  
17 necessary nasal pressure, has been a major goal of research aimed at  
18 improving patient compliance with therapy. Various systems for the treatment  
19 of obstructive sleep apnea are disclosed, for example, in "Reversal of  
20 Obstructive Sleep Apnea by Continuous Positive Airway Pressure Applied  
21 Through The Nares", Sullivan et al, Lancet, 1981, 1:862-865; and "Reversal Of  
22 The 'Pickwickian Syndrome' By Long-Term Use of Nocturnal Nasal-Airway  
23 Pressure"; Rapaport et al, New England Journal of Medicine, October 7, 1982.

24           The article "Induction of upper airway occlusion in sleeping individuals  
25 with subatmospheric nasal pressure", Schwartz et al, Journal of Applied  
26 Physiology, 1988, 64, pp 535-542, also discusses various polysomnographic  
27 techniques.

Despite its success, limitations to the use of nasal CPAP exist. These mostly take the form of discomfort from the mask and the nasal pressure required to obliterate the apneas. Systems for minimizing the discomfort from the mask are disclosed, for example, in U.S. Patent Nos. 4,655,213, Rapaport et al, and 5,065,756, Rapaport, as well as in "Therapeutic Options For Obstructive Sleep Apnea", Garay, Respiratory Management, Jul/Aug, 1987, pp 11-15; and "Techniques For Administering Nasal CPAP", Rapaport, Respiratory Management, Jul/Aug. 1987, pp 18-21. Minimizing the necessary pressure remains a goal of the preliminary testing of a patient in the sleep laboratory. However, it has been shown that this pressure varies throughout the night with sleep stage and body position. Furthermore, the therapeutic pressure may both rise or fall with time in patients with changing anatomy (Nasal congestion/polyps), change in weight, changing medication or with alcohol use. Because of this, most sleep laboratories currently prescribe the setting for home use of nasal CPAP pressure based upon the single highest value of pressures needed to obliterate apneas during a night of monitoring in the sleep laboratory. Retesting is often necessary if the patient complains of incomplete resolution of daytime sleepiness, and may reveal a change in the required pressure.

## SUMMARY OF THE INVENTION

The invention is therefore directed to a method and apparatus for minimizing the CPAP pressure, in a system for the treatment of obstructive sleep apnea, without causing limitation of airflow to the patient by partial airway obstruction to occur.

Briefly stated an apparatus for the treatment of obstructive sleep apnea is provided, comprising a source of air, and means for directing an air flow from said source to a patient. This part of the system may be of the type

disclosed, for example, in U.S. Patent No. 5,065,756. In accordance with the invention, means are provided for sensing the waveform of said airflow, to detect deviations therein that correspond to flow limitation in the air supplied to the patient. Such deviations may be, for example, deviations from a substantially sinusoidal waveform, flattening, or the presence of plateaus, in the portions of the waveform corresponding to inspiration of the patient. In response to such variations in said airflow, the system of the invention increases the airflow to the patient.

The system may be provided with a program that periodically decreases the airflow in the absence of detection of airflow limitation, and that periodically increases the airflow in the presence of detection of the airflow limitation.

In accordance with the method of the invention, the airflow to the patient is increased in response to the detection of waveform portions corresponding to flow limitations. The increases may be effected periodically. Similarly, the flow may be periodically decreased in the absence of such flow limitation.

#### BRIEF DESCRIPTION OF THE DRAWING

In order that the invention may be more clearly understood, it will now be disclosed in greater detail with reference to the accompanying drawing, wherein:

Fig. 1 is the waveform of the airflow of a 30 second epoch to a sleeping patient from a CPAP generator, with a CPAP pressure of 10 cm H<sub>2</sub>O;

Fig. 2 is the waveform of the airflow of a 30 second epoch to the sleeping patient of Fig. 1, from a CPAP generator, with a CPAP pressure of 8 cm H<sub>2</sub>O;

Fig. 3 is the waveform of the airflow of a 30 second epoch to the

1 sleeping patient of Fig. 1, from a CPAP generator, with a CPAP pressure of 6  
2 cm H<sub>2</sub>O;

3 Fig. 4 is the waveform of the airflow of a 30 second epoch to the  
4 sleeping patient of Fig. 1, from a CPAP generator, with a CPAP pressure of 4  
5 cm H<sub>2</sub>O;

6 Fig. 5 is the waveform of the airflow of a 30 second epoch to the  
7 sleeping patient of Fig. 1, from a CPAP generator, with a CPAP pressure of 2  
8 cm H<sub>2</sub>O;

9 Fig. 6 is a simplified cross sectional view of a Starling resistor;

10 Fig. 7 is a simplified block diagram of an experimental setup employing  
11 a Starling resistor;

12 Fig. 8 is a set of waveforms generated by use of the setup of Fig. 7;

13 Fig. 9 is a simplified block diagram of a system in accordance with the  
14 invention;

15 Fig. 10 is a flow diagram illustrating one technique for adjusting the  
16 CPAP pressure, in accordance with the invention.

#### 17 DETAILED DISCLOSURE OF THE INVENTION

18 Figs. 1-5 illustrate the waveforms of flow from a CPAP generator,  
19 obtained during the testing of a patient, in sleep studies. In these tests, the  
20 patient was wearing a CPAP mask connected to an air source, in the manner  
21 illustrated in U.S. Patent No. 5,065,765. Each of these tests illustrate an epoch  
22 of 30 seconds, with the vertical lines depicting seconds during the tests. Figs. 1-  
23 5 depict separate sweeps that were taken from 1 to 2 minutes apart, and with  
24 different pressures from the source of air.

25 Fig. 1 illustrates a "normal" waveform, in this instance with a CPAP  
26 pressure of 10 cm H<sub>2</sub>O. This pressure was identified as corresponding to  
27 obstruction free respiration. It is noted that this waveform, at least in the

1 inspiration periods, is substantially sinusoidal.

2 When the CPAP pressure was decreased to 8 cm H<sub>2</sub>O, as illustrated in  
3 Fig. 2, a partial flattening of the inspiratory flow, at regions 2a, began to occur.  
4 This flattening became more definite when the flow was decreased to 6 cm  
5 H<sub>2</sub>O, as illustrated by the reference numeral 3a in Fig. 3. The flattening  
6 becomes even more pronounced, as seen at the regions 4a of Fig. 4, when the  
7 flow was reduced to 4 cm. Reductions in the CPAP pressure from the pressure  
8 of obstruction free respiration resulted in snoring by the patient. When the  
9 flow was reduced to 2 cm H<sub>2</sub>O, as illustrated in Fig. 5, there was virtually zero  
10 inspiratory flow during the inspiratory effort, as seen at the portions 5a.  
11 Shortly after the recording of the waveform of Fig. 5, the patient developed  
12 frank apnea and awakened.

13 The waveforms of Figs. 1-5 illustrate that, as the pressure is lowered, a  
14 predictable index of increasing collapsibility of the airway occurs, prior to the  
15 occurrence of frank apnea, periodic breathing or arousal.

16 The waveforms of Figs. 1-5 are consistent with experiments wherein the  
17 collapsible segment of the air passage is simulated by a Starling resistor. A  
18 Starling resistor 10, as illustrated in Fig. 6, is comprised of a rigid external  
19 tube 11 supporting an internal collapsible tube 12. Water is introduced into  
20 the space between the outer tube 11 and inner tube 12, for example via a  
21 tube, from a water column 13 of adjustable height, to enable variation of the  
22 external pressure applied to the collapsible tube 12. In this experiment, a  
23 commercial CPAP flow generator 14 is coupled to the "distal" end of the  
24 Starling resistor 10, and "respiration" is simulated by a sinusoidal pump 15  
25 coupled to the "proximal" or "intrathoracic" end of the resistor 10. A volume  
26 reservoir 16 is coupled to the proximal end of the Starling resistor, to provide  
27 a capacitive volume that prevents excessive negative pressure from developing



1 during total system occlusion (apnea).

2 The flow tracing of Fig. 7 was generated using the system of Fig. 6, with  
3 the level of water in the column 13 set between 5 and 15 cm H<sub>2</sub>O. The airflow  
4 from the CPAP flow generator was started at 14 cm H<sub>2</sub>O, then sequentially  
5 decreased to 12 cm, 11 cm, 8 cm and 6 cm H<sub>2</sub>O, and finally returned to 13 cm  
6 H<sub>2</sub>O. In this figure, the upper curve shows the waveform of the airflow, the  
7 middle curve shows the waveform of the proximal pressure (i.e. at the port of  
8 the sinusoidal generator 15, and the lower curve illustrates the CPAP pressure.  
9 The gradations at the top of Fig. 7 denote seconds. Fig. 7 thus reflects the  
10 large increase in resistance across the Starling resistor, and mimics the  
11 increasingly negative intrathoracic pressure routinely seen in patients with an  
12 apnea, snoring and any increased airway resistance syndrome.

13 In accordance with the invention, analysis of waveforms of the flow of  
14 air, of the type illustrated in Figs. 1-5, is employed in order to control the flow  
15 of air from a CPAP generator, to thereby minimize the flow of air from the  
16 generator while still ensuring that flow limitation does not occur.

17 In one embodiment of the invention, as illustrated in Fig. 8, a CPAP  
18 mask 20 is connected via tube 21 to receive air from a CPAP flow generator  
19 22. These elements may be of the type disclosed in U.S. Patent No. 5,065,756,  
20 although the invention is not limited thereto, and any conventional CPAP  
21 system may alternatively be employed. A conventional flow sensor 23 is  
22 coupled to the tube 21, to provide an electric output signal corresponding to  
23 the waveform of the airflow in the tube 21. This signal is applied to a signal  
24 processor 24, which detects the existence in the waveforms of conditions that  
25 indicate flow limitation. The signal processor 24 outputs a signal to a  
26 conventional flow control 25 for controlling the pressure applied by the flow  
27 generator to the tube 21. It is of course apparent that, depending upon the

1 type of flow generator 22, the signal processor may directly control the flow  
2 generator, instead of controlling a flow control device 25.

3 One method for adjusting the CPAP pressure in accordance with the  
4 invention is illustrated in Fig. 10. After the CPAP mask has been fitted to a  
5 patient, and the CPAP generator has been connected to the mask, at step 40  
6 the CPAP pressure is set at a starting pressure. This pressure is a pressure at  
7 which flow limitation for the patient does not occur. After a settling period of  
8 about 30 seconds, at step 41, the flow signal is analyzed, at step 42.

9 If it is determined in step 43, that flow limitation has occurred, and the  
10 CPAP pressure is less than the maximum allowed as determined at step 44,  
11 the CPAP pressure is increased by 0.5 cm H<sub>2</sub>O, at step 45, and the procedure  
12 jumps back to the settling step 41 for further processing. If, at step 44, the  
13 pressure was not less than the maximum allowed CPAP pressure, the program  
14 jumps back to the settling step 41 without increasing the CPAP pressure.

15 If, at step 43, it was determined that a flow limitation was not present,  
16 then a determination is made, at step 46, if a predetermined time has elapsed  
17 following the last change in the CPAP pressure. The predetermined time may  
18 be, for example, two minutes. If the predetermined time has not elapsed, the  
19 program jumps back to the settling period of step 41. Otherwise, i.e. if the  
20 predetermined minimum time has elapsed, at step 47 it is determined whether  
21 or not the CPAP pressure is greater than the minimum allowed pressure. If it  
22 is greater than the minimum allowed pressure, then the CPAP pressure is  
23 decreased by 0.5 cm H<sub>2</sub>O, at step 48, and the program jumps to the settling  
24 step 41. Otherwise, the program jumps back to the settling step 41 without  
25 decreasing the CPAP pressure.

26 While the above described example of the method of the invention  
27 employed CPAP pressure change steps of 0.5 cm H<sub>2</sub>O, it is apparent that the

1 invention is not limited to steps of this magnitude. In addition, the steps are  
2 not necessarily equal throughout the range of adjustment.

3 In step 43, as above discussed, it was determined if flow limitation was  
4 present or not. This step may involve any of a number of waveform analysis  
5 procedures. For example, several indices of flow limitation and/or partial  
6 airway obstruction which can be used, singly or in combination, include:

7 1. The derivative of the flow signal equals zero.

8 2. The second derivative between peaks of the flow signal is zero for a  
9 prolonged interval.

10 3. The ratio of early inspirational flow to midinspirational flow is less  
11 than or equal to 1.

12 The following events, which are not necessarily indications of flow  
13 limitation, but do indicate obstructions, in the waveform analysis, may also be  
14 employed in the determination of flow limitation:

15 1. Reduced slope of the line connecting the peak inspiratory flow to the  
16 peak expiratory flow.

17 2. Steep upward or downward stroke ( $dV/dt$ ) of the flow signal.

18 3. Ratio of inspiratory flow to expiratory flow over 0.5.

19 Thus in accordance with the invention, indices of increased inspiratory  
20 effort may also be employed which are secondary to airway obstruction, in the  
21 face of which flow limitaion becomes more likely. It is evident that analyses  
22 of this type may be effected by conventional hardware or software. The  
23 invention, however, is not limited to the above specific techniques for  
24 determining divergence of the waveform from the normal non-flow limited  
25 waveform to a waveform indicating the presence of flow limitation.

26 While the invention has been disclosed and described with reference to  
27 a limited number of embodiments, it will be apparent that variations and

1        modification may be made therein, and it is therefore intended in the  
2        following claims to cover each such variation and modification as falls within  
3        the  
4        true spirit and scope of the invention.

**WHAT IS CLAIMED IS:**

1. In an apparatus for the treatment of obstructive sleep apnea, comprising a source of air, and means for directing an air flow from said source to a patient and establishing a pressure at the nose of the patient, the improvement comprising means for sensing the waveform of said airflow, and means responsive to a change in said waveform corresponding to increased upper airway obstruction or flow limitation, in the portions thereof corresponding to inspiration of the patient, for increasing the pressure of air from said source.

2. The apparatus of claim 1 wherein said means responsive to a change in said airflow comprises means for detecting flattening of said waveform in portions thereof corresponding to inspiration periods.

3. The apparatus of claim 1 wherein said means responsive to a change in said airflow comprising means for periodically reducing said airflow by predetermined amounts in the absence of variations in said waveform from a substantially sinusoidal waveform, and means for periodically increasing said airflow in predetermined amounts in the presence of divergence of said portions of said waveform from a substantially sinusoidal shape.

4. In an apparatus for the treatment of obstructive sleep apnea, comprising a source of air, and means for directing an air flow from said source to a patient, the improvement comprising means for sensing the waveform of said airflow, means for detecting plateaus in the portions of said waveform corresponding to inspiration of said patient, and means responsive to detection of said plateaus for increasing the pressure of air from said source.

5. The apparatus of claim 4 further comprising means responsive to the

absence of detection of said plateaus by said detecting means for periodically reducing said airflow, and said means responsive to the detection of said plateaus comprises means for periodically increasing the pressure of air from said source.

6. In an apparatus for the treatment of obstructive sleep apnea, comprising a source of air, and means for directing an air flow from said source to a patient, the improvement comprising means for sensing the waveform of said airflow, means for detecting flattening in the portions of said waveform corresponding to inspiration of said patient, and means responsive to detection of said flattening for increasing the pressure of air from said source.

7. The apparatus of claim 6 further comprising means responsive to the absence of detection of said flattening by said detecting means for periodically reducing said airflow, and said means responsive to the detection of said flattening comprises means for periodically increasing the flow and/or pressure of air from said source.

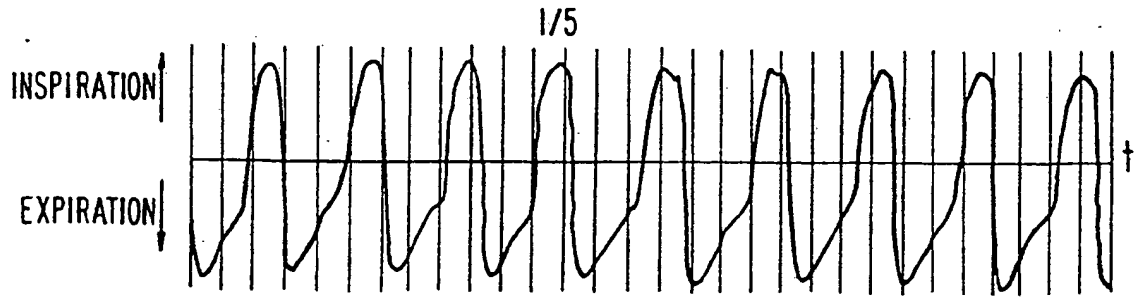
8. In the method for the treatment of obstructive sleep apnea comprising directing a flow of air to a patient and/or a pressure at the nose of the patient, the improvement comprising monitoring said flow of air to provide waveform signals, and increasing said flow of air and/or pressure in response to the occurrence, in said waveform signals, of signal deviations corresponding to flow limitation in the flow of air to said patient.

9. The method of claim 8 wherein said step of increasing said flow and/or pressure of air comprises increasing said flow and/or pressure of air in response to deviations of said waveform signals in the portions thereof corresponding to inspiration from said patient, from a substantially sinusoidal shape.

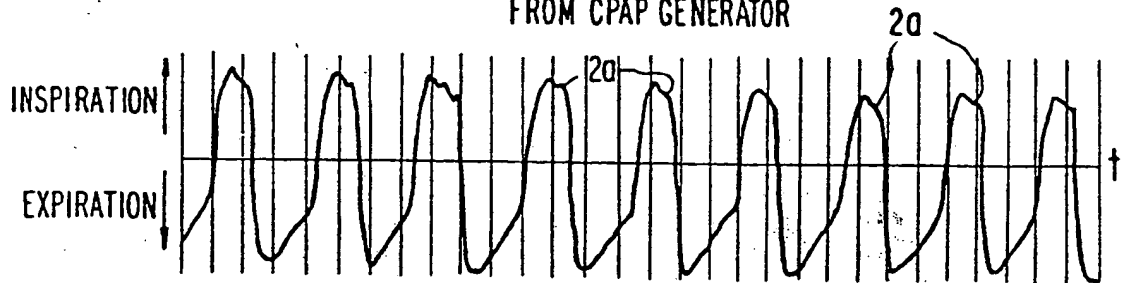
10. The method of claim 8 wherein said step of increasing said flow and/or pressure of air comprises increasing said flow and/or pressure of air in response to flattening of said waveform signals in the portions thereof corresponding to inspiration of said patient.

11. The method of claim 8 wherein said step of increasing said flow and/or pressure of air comprises increasing said flow and/or pressure of air in response to the occurrence of plateaus in the portions of said waveform signals corresponding to inspiration of said patient.

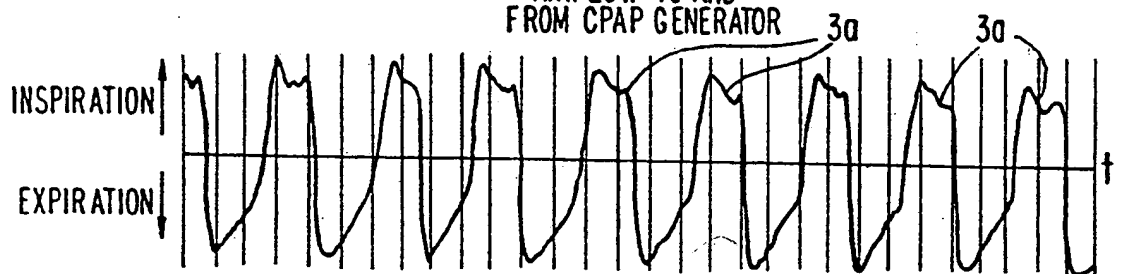
12. The method of claim 8 further comprising periodically decreasing said flow and/or pressure of air in the absence of the occurrence, in said waveform signals, of signal deviations corresponding to said flow limitation, and wherein said step of increasing said flow and/or pressure of air comprises periodically increasing said flow and/or pressure of air in response to the presence of waveform signals corresponding to said flow limitation, in order to seek the lowest effective pressure.



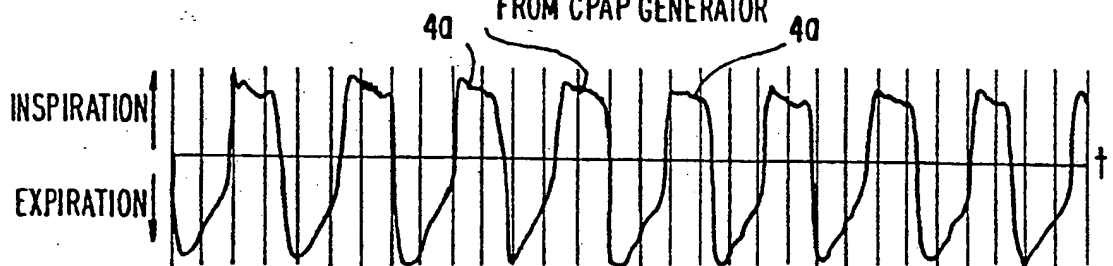
**FIG. 1**  
AIRFLOW TO AND  
FROM CPAP GENERATOR



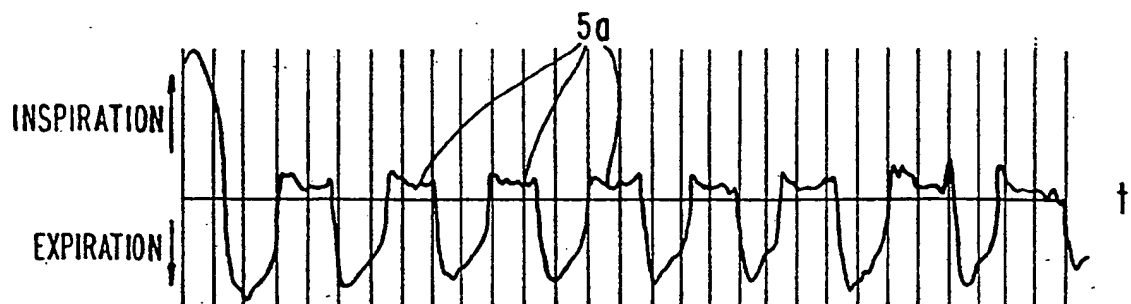
**FIG. 2**  
AIRFLOW TO AND  
FROM CPAP GENERATOR



**FIG. 3**  
AIRFLOW TO AND  
FROM CPAP GENERATOR

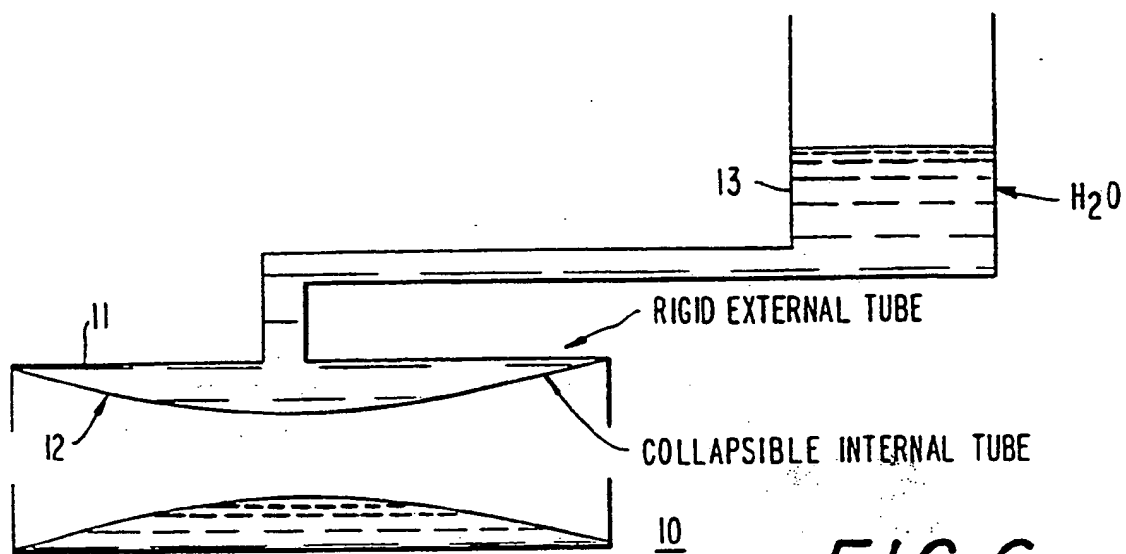


**FIG. 4**  
AIRFLOW TO AND  
FROM CPAP GENERATOR

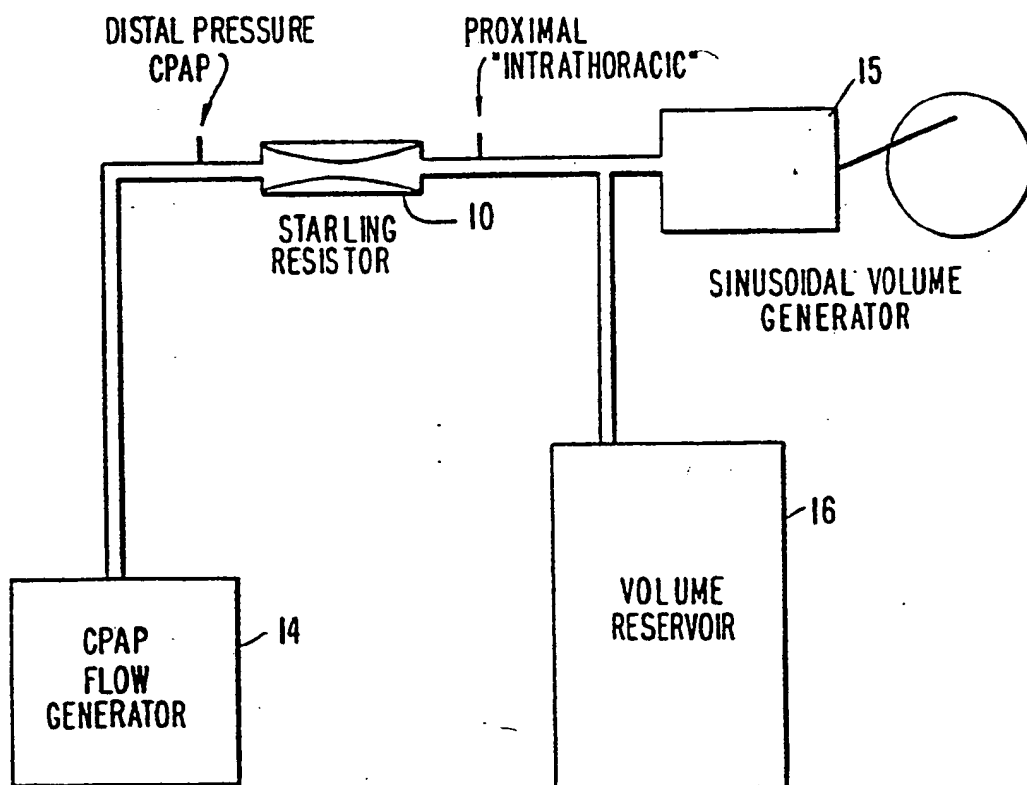


**FIG. 5**  
AIRFLOW TO AND  
FROM CPAP GENERATOR





**FIG. 6**



**FIG. 7**

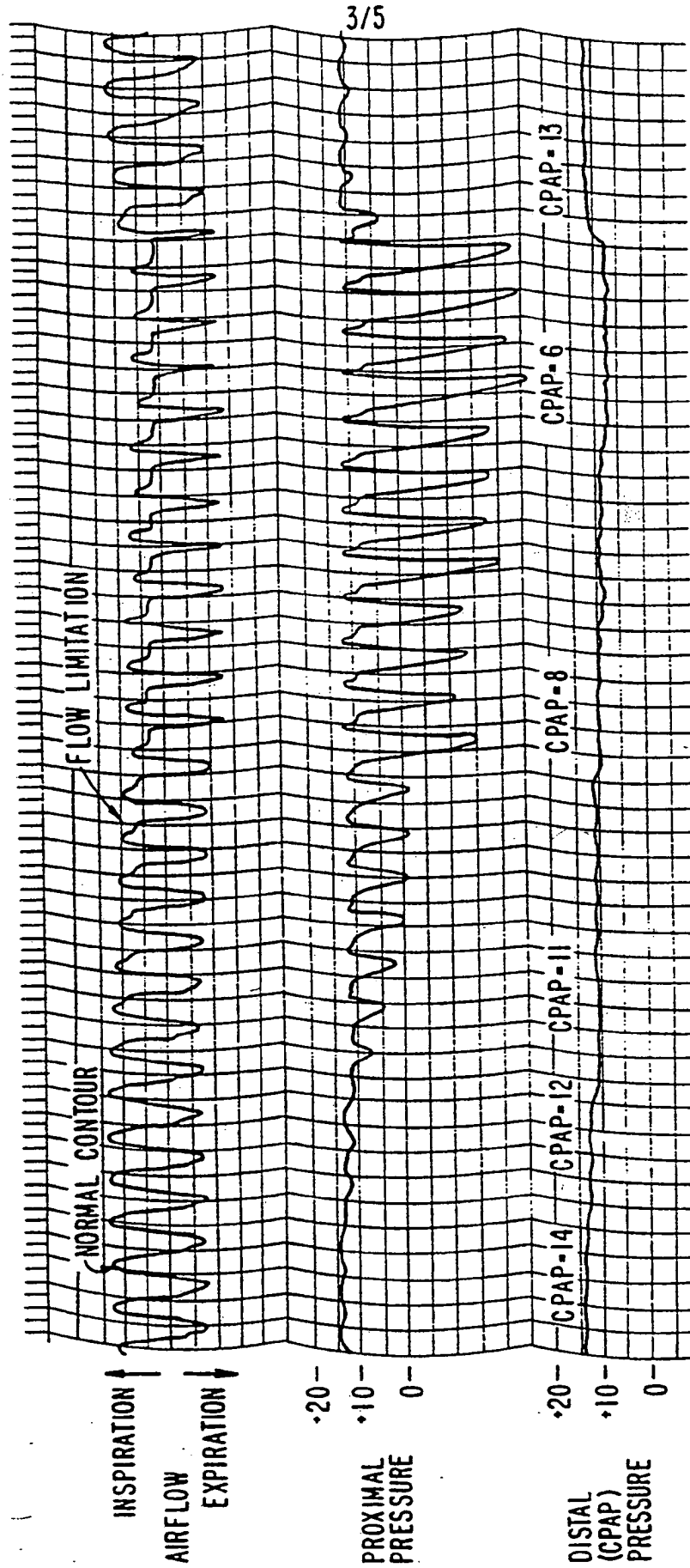
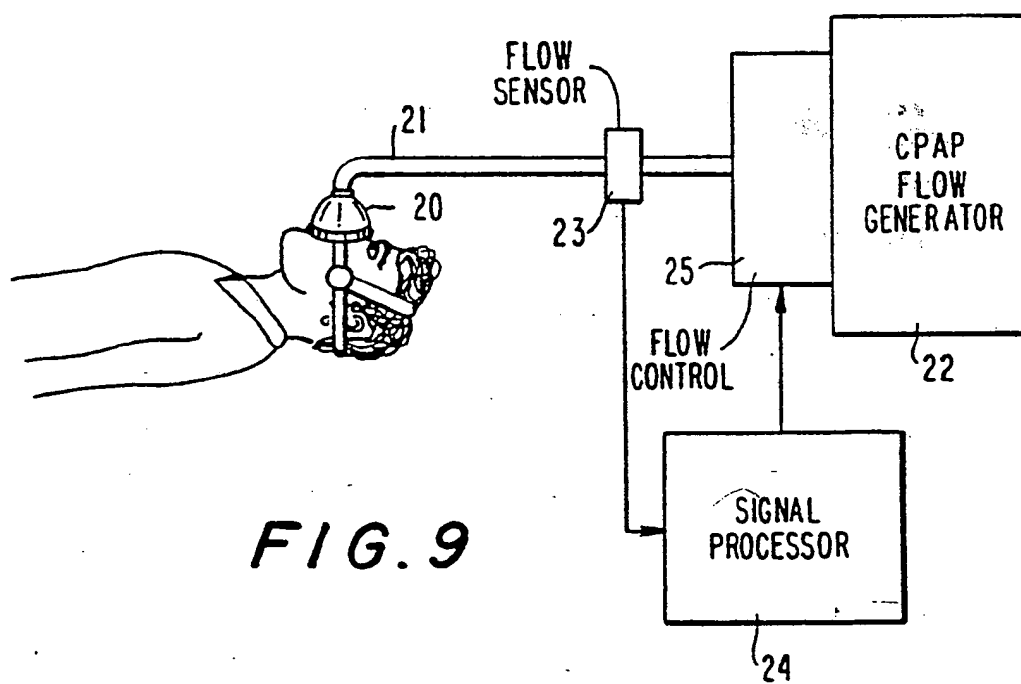
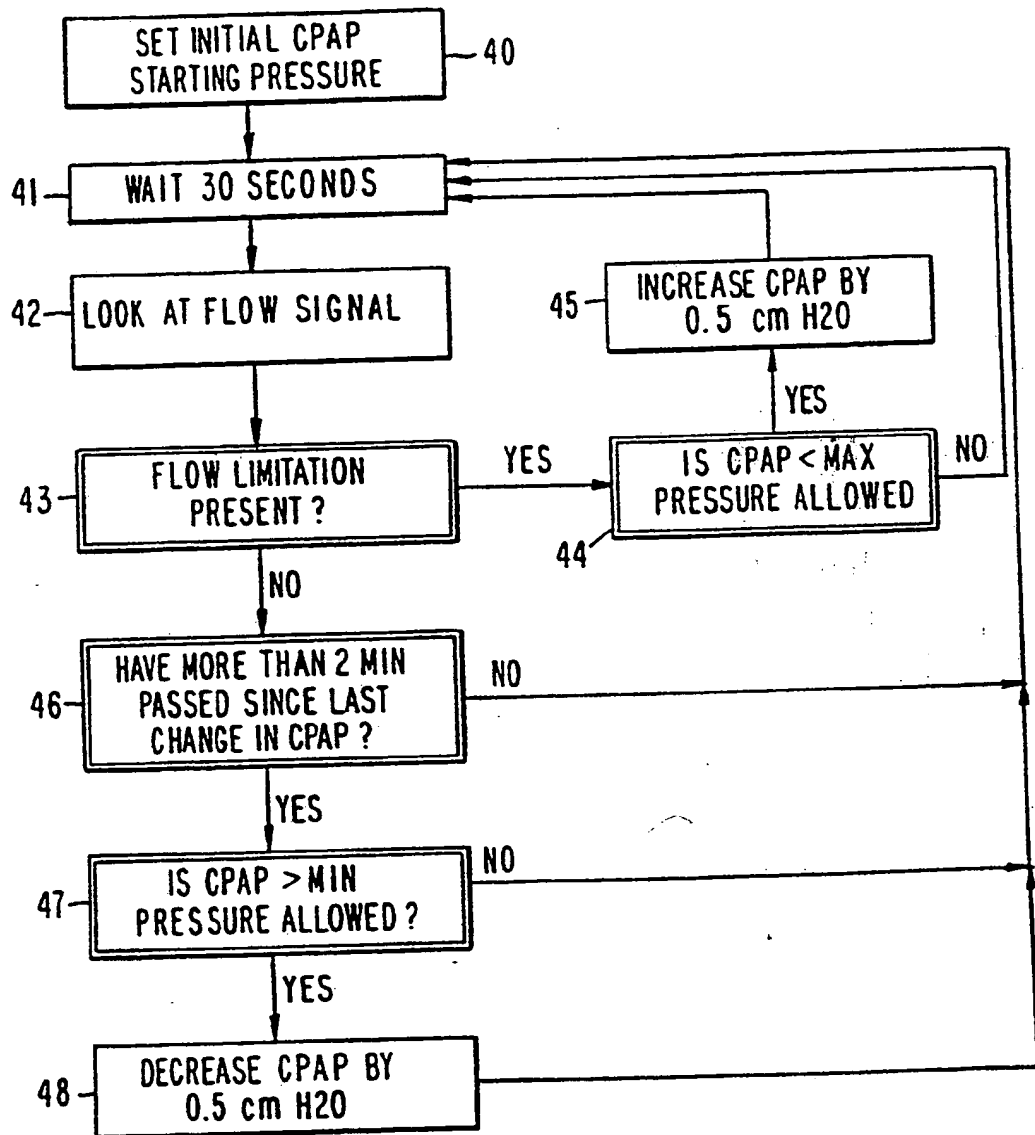


FIG. 8



*FIG. 10*

## INTERNATIONAL SEARCH REPORT

International application no.

PCT/US93/04367

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) : A61M 16/00

US CL : 128/204.23

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 128/204.18,204.21,204.26,205.18,207.18,716-726.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US,A, 5,107,831 (Halpern et al.) 28 April 1992 See entire document.	1-12
Y	US,A, 4,940,177 (Anderson et al.) 03 April 1984 See entire document.	1-12
Y	Ventilators: Theory & Application, 1986, Yvon Dupuis, pressure cycling, pp. 107-117.	1-12
Y	Digital Computation & Numerical Methods, 1965, Southworth et al. numerical analysis, pp. 6-10.	3,5,6,12

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

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11 JUNE 1993

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